Relativistic mean field study of neutron rich even-even C and Be isotopes

G. Gangopadhyay†§ and Subinit Roy‡

†Department of Physics, University of Calcutta, 92 Acharya Prafulla Chandra Road, Kolkata-700 009, India

‡Saha Institute of Nuclear Physics, Block AF, Sector 1, Kolkata- 700 064, India

Abstract. Ground state properties of neutron rich even-even Be and C nuclei have been investigated using Relativistic Mean Field approach in co-ordinate space. The positions of the neutron drip line are correctly predicted for both the elements. The nucleus ^{14}Be shows a two neutron halo but, contrary to expectation, ^{22}C does not exhibit any halo structure. In carbon nuclei, N=16 comes out as a new magic number. The single particle level ordering observed in stable nuclei is found to be modified in neutron rich Be isotopes. Elastic partial scattering cross sections for proton scattering in inverse kinematics have been calculated using the theoretically obtained densities for some of the nuclei and compared with available experimental data. The total cross cross sections for elastic scattering have also been calculated for all the nuclei studied showing a large increase for the halo nucleus ^{14}Be. The nuclei have also been investigated for deformation. The nuclei ^{10}Be and ^{16,18,20}C are observed to be deformed in their ground state.

§ Corresponding author (gautam@cucc.ernet.in)

1. Introduction

The last fifteen years have been an exciting time for nuclear physics. With the giant leaps in detection systems and accelerator technologies, particularly with the availability of radioactive ion beams, the old theories have been severely tested as never before. The limits of nuclear stability are now being probed and yielding surprising results. Major surprises in low energy nuclear structure include the disappearance of the normal shell closures observed near the stability valley along with the emergence of new magic numbers and neutron halo in nuclei very close to the drip line[1]. The effect of the halo may be observed in different reactions involving these nuclei. In particular, though electron scattering is the most direct probe of nuclear density, it is difficult to apply in nuclei far away from the valley of stability. Elastic proton scattering in inverse kinematics provides a test for the calculated densities[2]. In the present work, we study the structure of exotic even-even Be and C nuclei and calculate the elastic proton scattering cross sections using the theoretical densities.

Beryllium and carbon isotopes show a number of interesting features. The neutron drip line in beryllium is at ^{14}Be which is known to be a two-neutron halo nucleus. The drip line nucleus for carbon isotopes is ^{22}C which may also have a similar halo. It has also been suggested that N=16 is a new spherical magic number [3]. Our aim is to see how well Relativistic Mean Field (RMF) calculations can explain these different observed features in these nuclei.

There has been a number of nonrelativistic mean field calculations for the binding energy and radius in these nuclei[4]. Patra[5] has studied a number of light nuclei including Be and C isotopes using RMF approach. Ren *et al* have studied Be nuclei using density dependent RMF [6] and C [7] nuclei with RMF. The radius and binding energy of ^{14}Be have been reproduced in their calculation. Gmuca have studied various Be isotopes using the relativistic mean field approach[8]. Sharma *et al* [9] have studied the exotic carbon isotopes in a relativistic theory. Sugahara *et al* [10] have also studied these nuclei using relativistic and non-relativistic theories. Recently, deformed relativistic Hartree Bogoliubov (RHB) calculation employing the force NL3[11] in oscillator basis has also been performed to describe $^{11-14}$Be and $^{14-22}$C nuclei[12] among others. Most of the available calculations in this region use the harmonic oscillator basis. Spherical RHB approach has also been used [13] to study C nuclei.

Though there has been a number of calculations in the RMF approximation for Be and C nuclei, most of them use the harmonic oscillator basis. However, the basis expansion method may not be able to describe loosely bound states in halo nuclei. Calculations in RHB approach in r-space are also available. However, they are very involved and time consuming. We have used the co-ordinate space RMF+BCS approach to study these nuclei and to compare the results with thaose of RHB calculation in co-ordinate space.

2. Theory

RMF[14] calculation is now a standard tool to investigate the structure of the nucleus. It has been able to explain different features of stable and exotic nuclei like ground state binding energy, deformation, radius, excited states, spin-orbit splitting, neutron halo, etc[15]. Relativistic calculations have been known to give good description of nuclei near the drip line. For example, it has been possible to describe the halo in even the very light nuclei ^{11}Li[16]. This could be done without any artificial adjustment of the potential as required in the previous nonrelativistic calculations. Our aim is to see whether relativistic mean field calculations can also correctly describe the different features in Be and C nuclei. It is worthwhile to note that in ^{14}Be, the binding energy and radius could be reproduced in an RMF calculation[6]. The starting point is the relativistic Lagrangian for point nucleons interacting via exchange of the scalar-isoscalar meson σ, the vector-isoscalar meson ω, the vector-isovector meson ρ and the photon. RMF is known to give a good description of spin orbit splitting and is thus ideally suited for investigating the magic numbers in nuclei away from the stability valley. In recent years, efforts have been made to develop a energy density functional which will be applicable to all nuclei in their ground as well as excited states and to nuclear matter. Within the relativistic framework, effective interactions have been constructed with density dependent meson nucleon couplings[17] for this purpose. These recent developments are motivated by the fact that the success of the RMF approach is now explained from the point of view of effective field theory and the density functional theory. For example, the nonlinear terms in the Lagrangian are now considered to introduce additional density dependence in the energy functional. The parameters of the Lagrangian have been obtained by fitting different experimental observations and may be interpreted in this approach to already contain the vacuum contributions. In quantum hadrodynamics effective field theoretical Lagrangians explicitly include the basic symmetries of QCD and thus may be considered as its true representation in the low energy nuclear physics. The readers are referred to recent literature [18] for additional details.

In the conventional RMF+BCS approach for even-even nuclei, the Euler-Lagrange equations obtained are solved under the assumptions of classical meson fields, time reversal symmetry, no-sea contribution, etc. Pairing is introduced under the BCS approximation. Both constant gap and constant strength methods as well as other approaches in pairing have been used in different works. Very often the resulting equations are solved[19] in a harmonic oscillator basis. However, in exotic nuclei, the basis expansion method using harmonic oscillator, because of its incorrect asymptotic properties, faces problems in describing the loosely bound halo states. A solution of the Dirac and Klein Gordon equations in co-ordinate space may be preferable to describe the weakly bound states. Because these nuclei studied are very close to the drip line, one has to consider the effect of the positive energy states also. In this work, we have calculated the resonant state by studying localization of the scattering wave function except for the $\nu s_{1/2}$ state. This method has been applied in the nonrelativistic Hartree Fock [20]

as well as relativistic mean field formalism[22]. The $\nu s_{1/2}$ state could not be localized because there is no Coulomb or centrifugal barrier for this state. Thus we have to use the box normalization condition for the positive energy $\nu s_{1/2}$ state which occurs only in ^{10}Be among the nuclei studied in the present work. These positive energy levels are of finite width whose effect in pairing can be incorporated following Ref. [20]. However, because the contribution of these levels are expected to be small, we have assumed these levels to be of zero width at the resonance energy. In the very light mass region, where we are interested, pairing energy is very small. We have followed two procedures in pairing, both in constant gap approximation. In one we have taken the pairing gaps as $\Delta_p = \Delta_n = 0.2$. This prescription has been followed by Ren *et al* [7]. In the other we have adjusted the gap parameters so as to reproduce the pairing energy obtained in the spherical RHB calculation described below. This method has been successfully followed in many works[21]. We call these two procedures RMF-I and RMF-II, respectively. We find that there is very little difference between the two approaches.

A more accurate treatment of the drip line nuclei involves RHB approximation which has been studied in a number of previous works. We have compared the results of our RMF+BCS calculation with that of RHB approach using the same force NLSH. The RMF+BCS calculation is much simpler and less time consuming compared to a full RHB calculation. We want to compare the results of the two approaches, particularly for the density distribution. For the RHB calculation, we have used the code spnRHBfem[23]. For the finite range interaction, the $J = 0$ part of nonrelativistic Gogny interaction D1S[24] has been chosen.

The RMF+BCS approach in co-ordinate space was modified to study deformed nuclei also[25]. We have adopted this method to study the deformation of these nuclei. The quadrupole deformation parameter β_2 is calculated from the total quadrupole moment using the relation

$$Q_{n,p} = \sqrt{\frac{16\pi}{5}} \frac{3}{4\pi} (N, Z) R_0^2 \beta_{2n,p} \tag{1}$$

with R_0=1.2A$^{1/3}$fm.

We have applied the force NLSH[26] in the co-ordinate space RMF approach to calculate the ground state properties in neutron rich Be and C nuclei. We have also checked our results with the force NL3. However, as discussed later, we find that the agreement in binding energy, particularly for the drip line nuclei, is better in the case of the NLSH force.

Although electron scattering is the most direct method for measuring the density in stable nuclei[27], it is difficult to apply in regions far away from the valley of stability. Elastic proton scattering in inverse kinematics, alternatively, also provides a test for the calculated densities[2]. We have calculated the elastic scattering cross section for scattering of the nuclei from proton target at $55A$ MeV energy with the optical model potential (OMP) generated in a semi-microscopic approach. The OMP is

obtained using the effective interaction derived from the nuclear matter calculation of Jeukenne, Lejeune, and Mahaux (JLM)[28] in the local density approximation (LDA) by substituting the nuclear matter density with the calculated density distribution of the finite nucleus. Further improvement is incorporated in terms of the finite range of the effective interaction by including a Gaussian form factor. The calculation has been performed with the computer codes MOMCS[29] and ECIS95[30] assuming spherical symmetry. We have used the global parameters for the effective interaction and the respective default normalizations for the potential components from Refs. [29] and [31] with Gaussian range values of $t_{real} = t_{imag} = 1.2$ fm. No search has been performed on any of these parameters. It has been shown previously that JLM calculation can reproduce the proton plus unstable nucleus elastic scattering, when a realistic nuclear matter density distribution is used [2].

3. Results

We have studied the structure of ^{10,12,14}Be and ^{14,16,18,20,22}C. In Table 1 our results for binding energy and radius values in the spherical limit are given and compared with experimental measurements wherever available. All the theoretical values in this table have been calculated using the force NLSH. The calculated results for binding energy are in reasonable agreement with experimental measurements. Later we will show that this agreement improves with the inclusion of deformation degree of freedom. The results for different type of radii are in excellent agreement with experimental values in most of the cases. One can also see that the results of RMF-I calculation do not significantly differ from that of RHB calculation except for the radius of ^{14}Be where the latter is closer to the experimental value. Sandulescu *et al* [22] have pointed out that this difference is generally common near the drip line and can be attributed to the different ways of pairing calculation in the two methods. The occupancies of narrow resonances with high angular momenta is higher in RHB calculation. This is a consequence of the large energy cut off employed in the RHB (or HFB) approach which makes the Fermi sea more diffuse, thus increasing the scattering to loosely bound narrow resonances with high angular momenta. The RMF calculations, on the other hand, predict higher occupancy of broader low angular momentum resonances. The radius near the drip line is very sensitively dependent on the occupancy of the localized orbits. The high spin states are more localized due to larger centrifugal barrier. Increased occupancy for them translates into smaller radius for RHB calculation.

As expected, the RMF-II calculation gives a better agreement with the RHB calculation. In all the other features studied in the present approach in the spherical limit the three methods agree very well among themselves and we present the results of RMF-I only for them unless otherwise mentioned.

The single particle neutron levels in Be are given in Fig. 1. A level inversion occurs with the $2s_{1/2}$ state coming down below the $1d_{5/2}$ state. The former becomes weakly bound in ^{12,14}Be. This inversion is essential for the nucleus ^{14}Be to be bound. However,

neither the RMF+BCS scheme, nor the RHB approach can predict the parity inversion in neutron rich Be nuclei, which has been observed in ^{11}Be. This inversion also could not be explained by a full scale shell model calculation[35] and the authors of that work have suggested that the effect of three body forces should be included to explain the phenomenon. Although the RMF forces contain contributions from higher body forces, both the presently used parameterizations, *i.e.* NLSH and NL3 fail in this regard.

In Fig. 2, we plot the nucleon densities in ^{12,14}Be for a spherical calculation in co-ordinate space as well as the RHB result. The RMF+BCS densities are indicated by the solid lines, and the RHB densities, by the dashed lines. The proton densities are very similar in both the nuclei. The neutron halo in ^{14}Be is clearly seen in both the calculations.

The calculated single particle levels in ^{18,20,22}C are shown in Fig. 3. The RMF-I results are compared with those of RHB calculation. One can see that for the negative energy levels, the RMF+BCS calculation agrees very well with the more involved RHB approach. A difference between the single particle neutron structures of Be and C isotopes is readily seen. In C isotopes, the level inversion between the $1d_{5/2}$ and the $2s_{1/2}$ single neutron levels does not occur though the latter comes very close to the former. Another important difference is the binding energy of the last filled level. The $2s_{1/2}$ state is bound by more than 3 MeV. Hence, the wave function of this state does not extend to a very large value unlike the results of calculation in ^{14}Be and the predicted neutron radius is actually smaller than that expected for a halo nucleus.

The nucleon densities in ^{16,18,20,22}C have been shown in Fig. 4. Once again, the results of the RMF+BCS and the RHB calculations agree very well. Both the calculations indicate that the neutron density distribution of ^{20}C and ^{22}C are not substantially different. This is another aspect of the fact that according to our calculation, the nucleus ^{22}C does not have a two neutron halo. It has been suggested that the neutron number N=16 is the new magic number in neutron rich nuclei. In the present work, the gap between the $2s_{1/2}$ and the $1d_{3/2}$ level comes out to be nearly 5 MeV in accordance with the above prediction.

To check whether the results in the present calculation depend on the particular force chosen, we have compared the results of the NLSH force with those of another similar nonlinear force, NL3. We have followed the procedure of RMF-I, *i.e.* performed a constant gap calculation with $\Delta_n = \Delta_p = 0.2$. As mentioned earlier, the agreement in the case of binding energy obtained with the NL3 force is poorer, particularly as the neutron number increases. Thus, in the case of ^{12}Be, the predictions from NLSH and NL3 forces are 4.992 MeV and 5.086 MeV, respectively. Similarly, for ^{22}C, the corresponding values are 5.568 MeV and 5.662 MeV, respectively. However, the general pattern of the ground state properties, including the level inversion mentioned above, and the density are the same for both the forces.

In Fig. 5, the results of the model calculation for angular distribution of elastic scattering of ^{12,14}Be and ^{20,22}C from proton target in inverse kinematics with density distributions taken from the RMF calculation have been plotted. We have come across

only one experimental result for elastic scattering among all the nuclei, *viz.* for ^{12}Be at an energy of 55A MeV[36]. For all the results above the energy is taken to be 55A MeV. The theoretical results are compared with the experimental data taken from [36]. As is apparent from the above discussion, the density patterns obtained from RMF and RHB calculation are very similar. Hence, we find that the scattering cross sections obtained using those density profiles are nearly identical in the two cases and have shown the scattering cross section in the RMF approach only. One can see that the trend of the scattering angular distribution can be satisfactorily explained by the present calculation without any further adjustment of the parameters of the effective interaction. No other experimental data is available for elastic proton scattering for the nuclei studied in the present work. In Fig. 6, we have plotted the total cross sections for elastic proton scattering in inverse kinematics. The beam energy in each case is $55A$ MeV. The smooth lines show the $A^{2/3}$ behaviour. Although in both the chains, the calculated values show an increase over the $A^{2/3}$ behaviour, one can see that for ^{14}Be, there is a large increase in the total cross section over the corresponding value for ^{12}Be. In the case of C nuclei, the rise is more gradual, even for ^{20}C-^{22}C. This smooth rise in the cross section is due to the fact that our calculation does not predict a two neutron halo in ^{22}C. Thus an experimental measurement of total elastic scattering cross section can verify the presence or absence of two neutron halo in the dripline Be and C isotopes.

We have also studied the nuclei for deformation in RMF-I and RMF-II formalism. The nuclei ^{12}Be and ^{14,22}C are found to be spherical in agreement with the fact that the neutron number N=8 and N=16 are magic numbers. In this regard, our calculation agrees with the RHB results of Lalazissis *et al* [12]. We also have observed ^{14}Be to be spherical. All the other nuclei show varying degree of deformation. The results of our calculation for binding energy and quadrupole deformation after the inclusion of deformation are presented in Table 2. For deformed nuclei, the calculation selfconsistently converges to the two coexistent minima, prolate and oblate, according as one starts with a positive or a negative initial deformation. One can see that in all these nuclei, the agreement between the calculated binding energy and experimental measurements improve for deformed solutions. Also, in most cases the proton and neutron deformation are substantially different from each other. In all the deformed nuclei studied, solutions for prolate and oblate deformation are very close in energy. We find that our results agree with that of the deformed RHB calculation of [12] except in a few cases as discussed. The nucleus ^{10}Be, which has not been studied in Ref. [12], comes out to be strongly deformed. Here, the proton deformation is much larger than the corresponding neutron one. In ^{14}Be, because of the level inversion, the last two neutrons occupy the $2s_{1/2}$ level instead of the deformation driving Ω=5/2 orbital of the $1d_{5/2}$ level as expected from level ordering observed near stability valley. Hence its ground state comes out to be spherical in contrast to Ref. [12], where the ground state is obtained as strongly deformed. In ^{16}C, the prolate and the oblate solutions come out to be nearly degenerate. This was observed in Ref. [12] also. Similarly, in ^{18}C, although the ground state comes out to be prolate, the binding energy of the oblate solution is

only about 150 keV less. The nucleus ^{20}C is again observed to be oblate. In contrast, the deformed RHB calculation [12] suggests that both ^{18,20}C are oblate in their ground states. Lalazissis *et al* have noted that because of the close lying self-consistent minima, it is not always possible for the mean field theories to accurately predict the sign of the deformation. In all the deformed C isotopes, proton distribution is very weakly deformed while the neutron distribution, except for the case of the prolate solution in ^{20}C, show moderate to large deformation. For comparison with the density obtained in the spherical solution, we plot in Fig. 7, the monopole (L=0) and the quadrupole (L=2) components of the neutron and proton densities in ^{16}C from the deformed calculation as well as the densities obtained in the spherical approach, both using RMF-I. One can see that the monopole components of the deformed distribution is similar to the spherical results except at the core where the latter is slightly depressed for neutrons. At larger distances the neutron distribution has a substantial contribution coming from the quadrupole component.

To check whether the disagreement in the ground state shape in ^{14}Be between the present calculation and [12] is due to the different force used or the essentially different methods adopted, we have employed the NL3 force in our calculation. In the resultant prolate solution, the proton distribution is nearly spherical. On the other hand, the neutron distribution shows a prolate deformation with $\beta_{2n} = 0.16$ which corresponds to a small mass deformation $\beta_2 = 0.11$. In comparison, the RHB calculation of Lalazissis *et al* [12], have predicted a very large mass deformation (nearly 0.4). One of the reasons of this large difference may be the fact that the RHB calculation, as mentioned earlier, involves a large number of positive energy levels while the RMF+BCS calculation includes only a few levels around the Fermi energy.

Overall, we find that our results for binding energy and radii in all the C isotopes studied in the present calculation are in better agreement with experimental or empirical values than the oscillator basis calculation[9] which uses the forces NLSH or TM1. In ^{22}C, because of the new magic number N=16, our calculations predict a spherical ground state. It is also better than or comparable to other relativistic calculations[5, 7, 12] in oscillator basis in the Be isotopes using various forces in this regard. For example, the deformation values obtained in Carbon isotopes in the present approach are more in agreement with the RHB results than the oscillator basis calculations. Thus we may conclude that near the drip line co-ordinate space calculation in many cases is better than basis expansion approach and is comparable to the more involved RHB approach.

4. Summary and Conclusions

The structure of neutron-rich C and Be nuclei have been studied in co-ordinate space RMF calculation and compared with results of RHB approach. The position of the neutron drip line is correctly predicted in both the elements. In Be isotopes, the $\nu 2s_{1/2}$ level comes below the $\nu 1d_{5/2}$ level, providing the drip line nucleus ^{14}Be with a two neutron halo. On the other hand, in ^{22}C, this inversion does not occur. Moreover,

in ^{22}C the last filled level is bound by about more than 3 MeV and there is no two-neutron halo. The much simpler RMF+BCS approach agrees very well with the RHB results. The densities calculated have been used to construct optical model potentials for proton scattering. The calculated differential cross section for elastic proton scattering in inverse kinematics compares favourably with experiment. The total elastic scattering cross section values for different nuclei have also been calculated. It shows a sudden increase at the neutron halo nucleus ^{14}Be. We have also studied the effect of including the deformation degree of freedom. The nuclei ^{10}Be and ^{16,18,20}C come out to be deformed. The agreement of the prediction for ground state binding energy with experimental measurement improves substantially with the inclusion of deformation. Here again, the agreement with deformed RHB calculation is noteworthy. In many cases, the co-ordinate space calculations are seen to be better than basis expansion approach.

Acknowledgment

References

[1] See *e.g.* Jonson B 2004 *Phys. Rep.* **389** 1 and references therein.
[2] Alamanos N and Roussel-Chomaz P 1996 *Ann. Phys. Fr.* **21** 601
[3] Ozawa, A, Kobayashi T, Suzuki T, Yoshida K, Tanihata I 2000 *Phys. Rev. Lett.* **84** 5493
[4] See *e.g.* Sagawa H and Toki H 1987 *J. Phys. G: Nucl. Part. Phys.* **13** 453
    Li X and Heenen P -H 1996 *Phys. Rev. C* **54** 1617
    Shen Y -S and Ren Z 1996 *Phys. Rev. C* **54** 1158
    Bai X and Hu J 1997 *Phys. Rev. C* **56** 1410
    Bai X and Hu J 1997 *Phys. Lett.* **395B** 151
[5] Patra S K 1993 *Nucl. Phys.* **A559** 173 (1993)
[6] Ren Z, Xu G, Chen B, Ma Z and Mittig X 1995, *Phys. Lett.* **351B**, 11
    Ren Z, Mittig W, Chen B, Ma Z, Auger G and Xu G 1995 *Phys. Rev. C* **52**, R1764
[7] Ren Z, Zhu Z Y, Cai Y H and Xu G 1996 *Nucl. Phys.* **A605** 75
[8] Gmuca S 1997 *Acta. Phys. Hung. N.S.* **6** 99
[9] Sharma M M, Mythili S, and Farhan A R 1999 *Phys. Rev. C* **59** 1379
[10] Sugahara Y, Sumiyoshi K, Toki H, Ozawa A and Tanihata I 1996 *Prog. Theor. Phys. (Kyoto)* **96**, 1165
[11] Lalazissis G A, König J and Ring P 1997 *Phys. Rev. C* **55** 540
[12] Lalazissis G A, Vretenar D and Ring P 2004 *Eur. Phys. J.* A **22** 37
[13] Poschl W, Vretenar D, Lalazissis G A, and Ring P 1997 , *Phys. Rev. Lett.* **79**, 3841
    Meng J, Zhou S -G and Tanihata I 2002 *Phys. Lett.* **532B**, 209
[14] Duerr H -P 1955 *Phys. Rev.* **103** 469
    Boguta J and Bodmer A R 1977 *Nucl. Phys.* **A292** 413
    Serot B D and Walecka J D 1979 *Phys. Lett.* **87B** 172
[15] See *e.g.* Ring P 1996 *Prog. Part. Nucl. Phys.* **37** 193
[16] Meng J and Ring P 1996 *Phys. Rev. Lett.* **77** 3963 Meng J, Pöschl W and Ring P 1997 *Z. Phys.* **A 358** 123
[17] Nikšić T, Vretenar D and Ring P 2002 *Phys. Rev. C* **66** 064302
    Lalazissis G A, Nikšić T, Vretenar D and Ring P 2005 *Phys. Rev. C* **71** 024312
[18] See *e.g.* Furnstahl R J and Serot B D 2000 *Nucl. Phys.* **A 663&664** 513c
    Furnstahl R J and Serot B D 2000 *Nucl. Phys.* **A671** 447
    Furnstahl RJ 2004 *Lect. Notes Phys.* **641**, 1
[19] Gambhir Y K, Ring P and Thimet A 1990 *Ann. Phys., NY* **198** 132
[20] Sandulescu N, Van Giai N, Liotta R J 2000 *Phys. Rev. C* **61** 061301
[21] See *e.g.* Hemlatha M, Bhagwat A, Shrivastava A, Kailas S and Gambhir Y.K. 2004 *Phys. Rev. C* **70** 044320
[22] Sandulescu N, Geng L S, Toki H and Hillhouse G 2003 *Phys. Rev. C* **68** 054323
[23] Pöschl W, Vretenar D and Ring P 1997 *Comp. Phys. Comm.* **103** 217
[24] Berger J F, Girod M and Gogny D, *Nucl. Phys.* **A428**, 32 (1984)
[25] Gangopadhyay G 1999 *Phys. Rev. C.* **59**, 2541
[26] Sharma M M, Nagarajan M A, and Ring P 2003 *Phys. Lett.* **312B**, 377
[27] Frois B and Papanicolas C N 1987 *Ann. Rev. Nucl. Part. Sci.* **37** 133
[28] Jeukenne J P, Lejeune A and Mahaux C 1974 *Phys. Rev. C* **14**1391
[29] Baugei E, Commissariat a l'Energie Atomique, Bruyeres-Le-Chatel, France, v 1.01.
[30] Raynal J 1994 CEA report no. CEA-N-2772
[31] Bauge E, Delaroche J P and Girod M 2001 *Phys. Rev. C* **63**, 024607
[32] Audi G, Wapstra A H and Thibault C 2003 *Nucl. Phys.* **A729** 337
[33] Osawa A, Suzuki T and Tanihata I 2002 *Nucl. Phys.* **A 693** 32
[34] Liatard E *et al* 1990 *Europhys. Lett.* **13** 401
[35] Frossén C, Navrátil P, Ormand W E and Caurier E 2004 Arxiv Nuc. Th. 0412049.

[36] Korsheninnikov A A *et al* 1995 *Phys. Lett.* **343B**, 53

Table 1. Binding energy and radius in Be and C isotopes in the spherical approach for NLSH force. Experimental binding energy values are from the compilation [32]. Experimental r.m.s. radii values are from [33] and are results of Glauber model analysis in the optical limit. Experimental neutron radii for C isotopes are from [34].

$^A Z$		B.E./A(MeV)	Radius(fm)		
			r_p	r_n	r_{rms}
^{10}Be	Expt.	6.498			2.30(2)
	RMF-I	6.192	2.19	2.42	2.33
	RMF-II	6.192	2.19	2.42	2.33
	RHB	6.188	2.19	2.42	2.33
^{12}Be	Expt.	5.721			2.59(6)
	RMF-I	5.855	2.26	2.73	2.58
	RMF-II	5.847	2.26	2.72	2.58
	RHB	5.845	2.26	2.72	2.58
^{14}Be	Expt.	4.994			3.16(38)
	RMF-I	4.992	2.27	4.04	3.62
	RMF-II	4.985	2.27	4.05	3.63
	RHB	4.955	2.27	3.69	3.35
^{14}C	Expt.	7.520		2.70(10)	2.30(7)
	RMF-I	7.616	2.37	2.56	2.48
	RMF-II	7.616	2.38	2.56	2.48
	RHB	7.612	2.38	2.56	2.48
^{16}C	Expt.	6.922		2.89(9)	2.70(3)
	RMF-I	6.780	2.39	2.93	2.74
	RMF-II	6.765	2.39	2.88	2.71
	RHB	6.765	2.39	2.85	2.69
^{18}C	Expt.	6.426		3.06(29)	2.82(4)
	RMF-I	6.220	2.41	3.04	2.84
	RMF-II	6.211	2.41	3.02	2.82
	RHB	6.206	2.41	3.01	2.82
^{20}C	Expt.	5.959			2.98(5)
	RMF-I	5.843	2.43	3.16	2.96
	RMF-II	5.844	2.43	3.12	2.93
	RHB	5.843	2.43	3.12	2.93
^{22}C	Expt.	5.440[1]			
	RMF-I	5.568	2.45	3.38	3.15
	RMF-II	5.568	2.45	3.38	3.15
	RHB	5.565	2.45	3.36	3.14

[1] Estimated value

Table 2. Calculated binding energy and deformation(β) in Be and C isotopes. NLSH force has been used.

Nucleus	RMF-I				RMF-II			
	β_{2p}	β_{2n}	β_2	B.E./A MeV	β_{2p}	β_{2p}	β_2	B.E./A MeV
^{10}Be	0.36	0.14	0.23	6.398	0.37	0.14	0.23	6.415
	-0.24	-0.16	-0.19	6.365	-0.25	-0.17	-0.20	6.372
^{16}C	0.08	0.46	0.32	6.888	-0.11	-0.24	-0.19	6.904
	-0.11	-0.24	-0.19	6.879	0.08	0.47	0.32	6.902
^{18}C	0.09	0.40	0.30	6.387	0.09	0.39	0.29	6.375
	-0.12	-0.39	-0.30	6.381	-0.11	-0.37	-0.28	6.365
^{20}C	-0.11	-0.30	-0.25	5.968	-0.12	-0.31	-0.25	5.983
	0.04	0.14	0.11	5.865	0.03	0.12	0.09	5.865

List of Figure captions

Fig. 1 : Calculated single particle neutron states in ^{10,12,14}Be in the spherical approximation. See text for details.

Fig. 2 : Calculated proton and neutron densities in ^{12,14}Be in the spherical approximation. Neutron and proton densities are indicated by N and P, respectively. The solid (dashed) line represents results of RMF+BCS(RHB) calculations.

Fig. 3 : Calculated single particle neutron states in ^{18,20,22}C in the spherical approximation.

Fig. 4 : Calculated proton and neutron densities in ^{16,18,20,22}C in the spherical approximation. See caption of Fig. 2 for details.

Fig 5. : Partial cross section for the elastic proton scattering in inverse kinematics. Energy of the projectile is 55A MeV. Theoretical results are connected by the solid line. Experimental values are from [36].

Fig 6 : Total cross section for elastic proton scattering of different C and Be nuclei in inverse kinematics studied in the present work.

Fig. 7 : Neutron and proton densities obtained in deformed and spherical calculation in ^{16}C. Neutron and proton densities are indicated by N and P, respectively. See text for details.

density (fm^{-3})

^{20}C

^{22}C

N

N

P

P

density (fm^{-3})

^{16}C

^{18}C

N

N

P

P

r(fm)

r(fm)